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MEMORANDUM FOR PRS (In-House Publication)

FROM: PROI (STINFO) 16 Mar 2001

SUBJECT: Authorization for Release of Technical Information, Control Number: **AFRL-PR-ED-VG-2001-052**
Miller, T.C., "Crack Growth Data Collection and Reduction Methodology Survey"

JANNAF Critical Defect Assessment Panel **(Statement A)**
(Cocoa Beach, FL, 26-30 Mar 01) (Deadline: 26 Mar 2001)

CRACK GROWTH DATA COLLECTION AND REDUCTION METHODOLOGY SURVEY

30 Jan 01

Tim Miller

Engineer

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Complications in the Measurement Process

- Inhomogeneity of microstructure, large deformations, and material nonuniformity complicate the analysis of cracks in propellant
- Microstructure - void nucleation, growth, and coalescence at the crack tip causes sporadic crack growth
- Large deformations - blunting at crack tip and large dimensional changes make measuring crack size somewhat subjective
- Variation of specimen properties due to trouble maintaining uniformity during processing of large rocket grains also a problem

Purpose of This Survey

- These complications give the crack growth rates scatter. Some of the scatter reflects real instantaneous changes in crack speed, while some are related to the measurement techniques used
- Researchers have used different geometries, measurement procedures, and analysis techniques to try to obtain the most accurate results
- This study surveys these procedures to determine state-of-the-art for crack growth measurements

Crack Size Measurement Methods

- Specimen Geometries and Test Procedures
- Measurement of Crack Size
- Time Increments

Specimen Geometries and Test Procedures

- Common Factors
  - Constant Strain Rate Tests
  - Thin Specimens
- Variations - Specimen Geometry Choices
  - Biaxial Specimens
    - Advantages: Biaxial stress, ~~no end rotations~~
    - Disadvantages: Two crack tips, asymmetric growth
  - Edge notched specimens
    - Advantages: Single crack tip
    - Disadvantages: Rotation about "hinge point"
  - Subscale motor specimens
    - Advantages: Relates to motor well
    - Disadvantage: Difficult to make, also may not apply to other motors

Measurement of Crack Size

- Videotape measurements were the most common
  - Advantages: simple, no specialized equipment
  - Disadvantages: tedious, high strain rate tests requires expensive high speed video equipment
  - Both measuring off of monitor with ruler and digitizing of videotape were used for actual measures, no difference in accuracy was noted
- Transparent plastic sheet with grid lines also used
- Contact methods
  - Colored dyes
  - Card inserted into mouth of crack
  - Advantages: colored dyes give crack profile, neither method requires surface observation
  - Disadvantages: limited number of measurements, must be measured during test manually, requires contact with propellant

Time Increments

Researchers did not report any typical time increments, there were no standard guidelines used, and the choice of time increment was left to the discretion of the investigator

Methods of Determining Crack Speed

Secant methods: most popular methods, advantages are simplicity and ease of use, disadvantages are scatter in data

Secant method $$\left.\frac{da}{dt}\right|_{t=t_i} = \frac{a_{i+1} - a_i}{t_{i+1} - t_i}$$

Modified secant method $$\left.\frac{da}{dt}\right|_{t=t_i} = \frac{1}{2}\left[\frac{a_i - a_{i-1}}{t_i - t_{i-1}} + \frac{a_{i+1} - a_i}{t_{i+1} - t_i}\right]$$

Polynomial methods: somewhat less popular, advantages are the "smoothing" of the data, somewhat more difficult to use

Incremental polynomial method or spline fitting method

Total polynomial method

Relation of Crack Speed to Loading

General Consensus: Power law relationship for crack speed and K

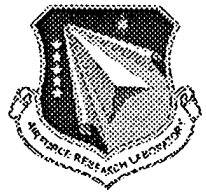
$$\frac{da}{dt} = CK^m$$

However, in one case crack size vs. time was used to determine the crack length at any particular time in the motor, and crack speed was never an issue

Potential Sources of Error

- Presence of two crack tips in biaxial specimen
- Accurate measurement of boundary conditions and loads
- Lack of well defined crack tip makes length measurement difficult
- Surface measurements may not represent crack size
- Possibility of parallax in measurements made through sight ports in pressure chambers

Summary



- Experimental procedures usually employ constant strain rates with thin specimens and crack sizes measured from the surface of the specimens
- The biaxial specimen was popular but had problems because of the dual crack tips. Other specimens have been used that have single crack tips, and analog or subscale tests have also been used
- Crack speed was determined from the crack size vs. time data using derivative approximations, the most common of which was the secant method, although researchers also used polynomial methods
- No guidelines other than engineer's judgement for time intervals
- Potential errors can be grouped in three categories:
  - Presence of two crack tips in biaxial specimens
  - Use of idealized boundary conditions in fracture calculations
  - Difficulties measuring the crack size accurately given that the crack tip is sometimes poorly defined and the interior of the crack front is not visible